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II. Bread Mixing Studies.

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Dairy Research Inc.,
and Eugene J. Guy
Dairy Products Laboratory,
Agricultural Research Service,
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ACID WHEY, by-product of cottage cheese manufacture, contains high quality protein and minerals as well as a sizable quantity of lactose. Current interest in the utilization of acid or cottage cheese whey stems from a growing environmental concern to halt industrial waste and subsequent environmental pollution. The ecology movement has given impetus to methods for utilizing these valuable nutrients.

Several unique food products which utilize whey have been developed. One of these is a sourdough-type bread (1). The pungent flavor characteristics of this bread are derived from the lactic acid in the whey, plus some added vinegar. These acids are produced in conventional sourdough during the long fermentation period. The addition of these acids as part of the dough ingredients reduces process time significantly and improves uniformity, which is most attractive to commercial bakeries. Many were interested in expanding into the growing specialty bread market, but unwilling to cope with conventional sourdough methods.

Several bakeries expressed interest in manufacturing this bread, but problems became apparent when low-energy horizontal mixers were used in its production. Since these same mixers were used successfully by bakers to make other hearth breads, we examined the components of our dough system and their effects on the farinograph mixing requirements.

Review of the literature indicated that pH affected the farinograph mixing of wheaten doughs (2). As pH decreased, mixing time was increased, consistency decreased, and doughs became sticky and less cohesive. At pH 4.6 doughs were fragile and tore easily. Tanaka *et al.* (3) showed that dough systems at pH 4.8 had greater farinograph stability than at pH 5.0 or 5.1, especially with added salt. The development time was not affected measurably in this pH range. These authors also showed that acid alone increased dough consistency, but in the presence of salt, dough consistency was decreased.

Since no information was available on the combined effects of acid, lactose, and salt, the farinograph was used to study these factors and their effects on the dough system.

Materials and Methods

A Brabender Do-Corder, Model PL-V3AA, equipped with a farinograph PL-2H mixing head, was used to investigate the effects of salt, acid whey, lactose, pH, flour, and mixing speed on the dough system. The 300-g constant flour weight procedure (5) was used with the bowl set 30°C. Sufficient water was titrated into the farinograph bowl to center the curve on the 500 BU line. All absorptions were corrected to a 480-g dough weight by the method of Stamberg and Merritt (6). Using their calculation, every 20 g of dough weight above 480 g adds 20 BU to the farinograph curve which is equivalent to 0.6 per cent water absorption (5). Farinograph speed was 63 r.p.m. except where a specific speed is indicated.

The sour dough system was made up in accordance with the 68/32 per cent lactic:acetic acid ratio as described by Shenkenberg *et al.* (1) Formulas were calculated on the basis of 300 g of flour. The level of acid whey was adjusted to achieve a final acidity of 0.09 meq/g dough. On this basis, 8.6 per cent acid whey was added to the formula. This amount of whey contains approximately 5.6 per cent lactose. The farinograph sourdoughs were made up with 8.6 per cent whey, 1.1 per cent 300 grain vinegar and 1.5 per cent salt. No yeast, malt or shortening was used in the farinograph.

A commercial hard red spring

wheat (HRS) flour of 14.6 per cent protein (N x 5.7) that was malted, bleached, and bromated was used. A combination of 50 per cent HRS with 50 per cent of a weaker hard red winter wheat (HRW) flour of 12 per cent protein (N x 5.7) that was bleached and malted also was used.

Spray-dried, high-heat commercial acid whey, with 86 per cent denatured protein, was used. This sample contained 9.1 per cent acidity expressed as lactic acid. The acetic acid was used in the form of 300 grain distilled vinegar (30 per cent acetic acid).

Cysteine monohydrochloride (hydrate) and sodium acetate buffer (anhydrous) were added directly to the dough system. Lactic acid (85 per cent) was added with the formula water.

The pH of doughs was taken by immersing the electrodes of the Beckman Zeromatic pH meter directly in the doughs after mixing.

Table I

Effect of Salt and Acid Whey Components on Farinograph Characteristics of Sourdough (SD)

				Minutes		
Item	Dough (HRS)	pH	Absorption (%)	Arrival	Peak	Stability
1	Flour alone	5.9	62.0	2.5	7.0	8.0
2	1.5% NaCl	5.9	58.1	2.5	8.0	13.0
3	5.6% lactose	5.9	59.5	1.5	7.0	11.0
4	5.6% lactose, 1.5% NaCl	5.9	55.7	2.0	10.5	18.0
5	8.6% AW	5.0	58.2	3.5	7.5	8.5
6	8.6% AW, 1.5% NaCl	4.9	54.4	3.0	12.5	19.0
7	8.6% AW, 1.1% vinegar	4.6	58.7	3.5	6.5	6.5
8	8.6% AW, 1.1% vinegar 1.5% NaCl (SD formula)	4.6	52.7	1.5	12.0	23.0
9	5.6% lactose, HLA, 1.1% vinegar (Simulated SD)	4.6	55.3	1.5	12.0	19.0
10	HLA, 1.1% vinegar 1.5% salt	4.6	54.0	2.0	9.0	16.0
11	SD System, 0.15% NaAc buffer	4.7	53.5	2.0	12.0	20.0

HRS = Hard Red Spring Wheat Flour; AW = Acid Whey; HLA = Lactic Acid, 85%; NaAc = sodium acetate.

Table II

Effect of Flour Type on the Farinograph Characteristics of Sourdough (SD)

		Minutes		
Dough	Absorption (%)	Arrival	Peak	Stability
HRS	62.0	2.5	7.0	8.0
HRS in SD formula	52.7	1.5	12.0	23.0
½ HRS ½ HRW	60.5	3.5	6.0	5.0
½ HRS ½ HRS in SD formula	52.1	1.5	11.5	19.5

Results and Discussion

Effect of Salt and Acid Whey Components

Table I shows that the addition of salt to HRS flour reduced the absorption and improved stability. Peak time was not greatly affected by the addition of salt. Lactose modified absorption and stability values less but in the same direction as salt. However, the combination of salt with 5.6 per cent lactose (Item 4), depressed dough absorption further and increased both dough development time and stability. Apparently the combination of salt with lactose has a greater effect than either lactose or salt have separately on the dough farinogram characteristics. Arrival time remains about the same; however, peak time, or the dough mixing requirement, is increased. Dough stability is also increased beyond the level of either salt or lactose added separately to the dough.

The table shows the farinogram of flour with 8.6 per cent acid whey (Item 5) resembled the farinogram of flour (Item 1) with similar peak times and stability. However, with the addition of salt, the acid whey dough system (Item 6) produced a farinogram resembling that of 5.6 per cent lactose with salt (Item 4). Again, the combination of salt with acid whey had a greater effect on farinogram characteristics than either salt or acid whey acting independently.

The sourdough system made with 8.6 per cent acid whey, 1.1 per cent 300-grain vinegar (0.09 meq acid/g dough) and 1.5 per cent salt (Item 7) had almost twice the mixing requirement of the same system made without salt (Item 8). Without salt, the dough development time of the sourdough system was equivalent to that of flour alone. With salt, dough stability was greatly increased and absorption decreased.

A simulated sourdough system made without acid whey, but with 5.6 per cent lactose and lactic acid as the whey replacement (Item 9), had farinograph characteristics, other than its slightly higher absorption, almost identical to the regular sourdough (Item 7). This indicates that the whey proteins and whey salts from acid whey can decrease dough absorption, but that they have a minimal effect on other farinograph characteristics. Removal of the lactose from this system slightly decreased absorption, peak time and stability of values (Item 10).

Effects of pH

Decreasing the pH of doughs from 5.9 to 4.9 or 5.0 by replacing lactose with acid whey (Items 3 and 4 compared respectively to 5 and 6) did not have a significant effect on farinogram characteristics.

The sourdough system containing acid whey, vinegar, and salt at pH 4.6 (Item 8) has about the same mixing requirement as the lactose and salt system at pH 5.9 (Item 4). Without salt, at pH 4.6, the sourdough system (Item 7) has the same mixing requirement as flour alone (Item 1).

Increasing dough pH from 4.7 to 4.6 with sodium acetate buffer did not have a significant effect on the dough characteristics (Item 8 compared to Item 11).

Effect of Flour

A lower protein HRW flour was used in combination with HRS flour. **Table II** shows the mixture of flours

Table III

Effect of Mixing Speed on Farinograph Characteristics of HRS Sourdoughs at pH 4.6

		Minutes		
Speed (rpm)	Absorption (%)	Arrival	Peak	Stability
50	52.7	5.0	25.0	37.0
63	53.5	1.5	12.0	23.2
80	56.0	4.0	10.0	13.5
100	58.2	5.5	8.0	7.0
126	60.0	3.5	7.0	5.5

Table IV

Effect of Cysteine and pH Variation on Farinograph Characteristics of Sourdoughs

			Minutes		
	pH	Absorption (%)	Arrival	Peak	Stability
HRS in SD formula	4.6	52.7	1.5	12.0	23.2
HRS in SD formula, 80 ppm cysteine	4.6	55.5	2.0	10.0	16.0
HRS + SD formula, 80 ppm cysteine, 0.15% NaAc	4.7	53.7	3.0	7.5	12.0
½ HRW ½ HRS in SD formula	4.6	52.1	1.5	11.5	19.5
½ HRW ½ HRS in SD formula, 80 ppm cysteine	4.6	54.2	2.0	7.0	9.0
½ HRW ½ HRS in SD formula, 80 ppm cysteine, 0.15% NaAc	4.7	54.1	2.1	6.5	8.5

had lower absorption and slightly reduced peak times and stability. The combination of flours in the sourdough formula had essentially the same mixing requirements and absorption as the HRS flour formula. Stability was reduced slightly with the addition of HRW flour.

Effects of Mixing Speed

To illustrate the effects of mixing speed on the sourdough system, the farinograph was operated at 50, 63, 80, 100, and 126 r.p.m. **Table III** indicates that as speed is increased, absorption is increased, which agrees with our observations and those previously reported by Hlynka (7). In addition, as speed is increased, peak times, and stability were reduced. The mixing requirement at 50 r.p.m. is twice that at 63 r.p.m. These results have practical implications for bakery work. The increased absorption and reduced mixing time at high speed would improve economy of operation.

Effects of Cysteine

Research on chemically accelerated dough systems revealed that the energy required for optimum dough development could be reduced by chemically cleaving or reducing disulfide bonds. Cysteine hydrochloride has been suggested as the most suitable reducing agent for splitting disulfide bonds (8). **Table IV** shows that addition of 80 ppm cysteine (an optimal level for bread) to the sourdough system increased water absorption and decreased development time for both the HRS and the combination of HRS and HRW flours.

When cysteine was present in the acid dough system, raising the pH altered the farinograms. With 80 ppm cysteine in HRS flour, changing the pH from 4.6 to 4.7 by addition of sodium acetate cut mixing requirements by 25 per cent. Raising the pH of the dough system with equal parts of HRS and HRW flours did not appreciably change the mixing characteristics.

Conclusions

The farinograph studies implicated a combination of factors contributing to the dough mixing requirements. Lactose and acid whey alone did not have a significant effect on the mixing requirement. With the addition of salt, to either lactose or acid whey, mixing times were extended. Either factor alone, salt, lactose, or acid whey did not have as great an effect on the dough system.

The effects of pH on the mixing requirements were minimal. Th sour dough system with 5.6 per cent lactose and 1.5 per cent salt exhibited essentially the same farinograph characteristics at pH 5.9 or 4.6. The mixing requirement was only reduced slightly at pH 5.9. The dough absorption was reduced at lower pH. Dough stability increased at lower pH with salt and lactose present, but decreased at low pH when salt and lactose were omitted.

The results of this farinograph work suggest that the significant effects of salt and lactose on the dough mixing requirement can be overcome by using a high speed mixer or by adding cysteine to the dough system. Increased mixing speeds up to 126 r.p.m. improved dough absorption and reduced the mixing requirements with both lactose and salt present. Cysteine had a similar but less pronounced effect on the dough system. Where a high speed mixer is not available, the addition of cysteine to the dough system is recommended as a means of reducing the mixing requirements.

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As MENTIONED in Part I, some commercial bakeries had difficulty in mixing the sourdough system. This dough system did not develop when mixed in low-energy horizontal mixers at 40 to 60 r.p.m. Since these low-energy mixers could successfully mix other dough systems we examined the effects of the various ingredients on the mixing of these doughs. In Part I, the farinograph was used to study the effects of acid, salt, and lactose on the mixing requirements of flours.

Part II reports on a bread mixing and baking study that supplements the farinograph data. The effects of salt, lactose, and pH on the mixing requirements were observed using a low-energy mixer. The doughs were fermented, proofed, baked, and then evaluated. Methods to reduce mixing requirements in low-energy mixers also were explored.

Materials and Methods

A small Hobart, Model N-50 with the dough hook attachment was used to simulate mixing in a low-energy horizontal mixer. The Hobart A-200, at 120 r.p.m., with the McDuffee bowl and fork attachment was used for the control bread.

The materials used were described in Part I. A commercial fat-coated salt also was used to evaluate the effects of withholding salt from the dough formula.

The bread formula was based on 700 g of flour using the straight dough method as outlined by Shenkenberg *et al.* (1). The level of acid whey was adjusted to a final acidity of 0.09 meq acid/g dough. The per cent acid whey added to this formula (based on flour) was 8.6 per cent. The lactic to acetic acid ratio was 68:32 per cent.

Mixing proceeded for two minutes on speed 1 followed by variable time on speed 2. Optimum development was judged by the baker. Fermentation and proofing were carried out at 95°-100°F. The fermentation and proof times were varied as indicated in **Table II.** Loaf volume was measured by rapeseed displacement after the loaves cooled for one hour.

The effects of salt on mixing requirements were investigated by omitting salt from the formula, by withholding salt to the end of the mixing period, and by using a fat-coated salt. The latter two methods also were used to reduce the dough mixing requirements. The effects of pH change were investigated by adding sodium acetate buffer to the system. Lactose were also added to some doughs.

Additional efforts to decrease the dough mixing requirements included increasing the dough floor time and adding cysteine monohydrochloride.

Carbon dioxide production was measured on doughs in which the salt was withheld and the coated salt was used. The studies were run at 30°C. A 17.30-g portion of dough containing all the formula ingredients was scaled into 2-oz. wax paper cups. The cups were placed inside standard volume mercury manometer pressuremeter vessels which were then sealed. The vessels were held five minutes, degassed, and measurements were taken. Readings were recorded at one and two hours. Two hours is about the time the doughs would be fermented and proofed before being baked.

Table I

Effect of Different Mixers on Dough and Bread Characteristics

Characteristics	Mixers: Hobart A-200	Hobart N50
Absorption	60%	57%
Mix time	1L 10S	2L 45S
Fermentation	40 min. at 95-100°F	40 min. at 95-100°F
Proof	60 min. at 95-100°F	60 min. at 95-100°F
Specific Volume	3.3-3.7 cc/g	2.6-3.0 cc/g
pH	4.6	4.6
Acidity	0.09 meq/g	
	38% acetic	same
	62% lactic	same

L = low speed; S = second speed.

Results and Discussion

The Effect of Mixing

Table I compares the characteristics of the doughs and their breads. These doughs were mixed to opti-

Table II

Effects of Variations in Mixing, Fermentation, and Proof Times of Doughs Mixed in the Hobart N50 Mixer

Mix Time (min.)	Dough Characteristics	Fermentation (min.)	Proof (min.)	Specific Volume (cc/g)
2L 22S	undermixed	40	60	2.5
2L 35S	"	90	90	2.5
2L 35S	"	90	60	2.5
2L 45S	some development	40	60	2.8
2L 45S	"	40	110	3.3

L = low speed; S = second speed.

Table III

Effects of Delayed Salt Addition or Using a Coated Salt on Mixing Times of Doughs

Variable	Proof (min.)	Specific Volume (cc/g)
NaCl at beginning	60	2.8
No NaCl	60	3.5
Delayed addition of NaCl	60	2.9-3.0
Delayed addition of NaCl	75	3.1
Delayed addition of NaCl	90	3.3
Delayed addition of NaCl	105	3.4
Delayed addition of NaCl	120	3.4
Coated NaCl	60	2.7
Delayed addition of coated NaCl	60	3.0

Absorptions — all 57%
Minutes Fermentation Time — all 40 minutes
Minutes Mixing Time: 1L 45S — first sample
Hobart N50: 1L 20S — rest of samples

Table IV

Effect of Variations in Salt and Times of Addition of Salt on Gas Production of Doughs and Specific Loaf Volume

Dough System	mmHg-1 hr.	mmHg-2 hr.	Difference Ratio 2/1 hr.	Specific Loaf Volume (cc/g)
Control dough, NaCl at beginning: A-200 mixer	55	113	2.05	3.3
No NaCl added: N50 mixer	98	195	1.99	3.5
Delayed addition of NaCl: N50 mixer	61	125	2.05	2.9
Coated NaCl at beginning: N50 mixer	72	140	1.94	2.6
Delayed addition of coated NaCl: N50 mixer	81	156	1.92	3.0

mum development in either the Hobart A 200 mixer or the Hobart N50 mixer.

In the Hobart N50, which simulated the low-energy commercial mixers, absorption decreased, the mixing time was extended unreasonably and bread volume dropped to produce an unacceptable loaf. Since the fermentation rates are not a function of mixing, the lower volumes probably were due to poor CO_2 retention as a function of undermixing.

Table II shows that variations in times of mixing, as well as proof times of the doughs mixed in the N50 mixer, affect specific volumes of breads. All doughs mixed for less than 45 minutes produced loaves which were very compact and low in volume irrespective of increased fermentation and/or proof times. Only doughs which had attained an adequate degree of development in the mixer responded to the increased proof time. This is related to the ability of the dough system to retain the gases produced. However, a mixing time of 45 minutes or more with a long proof time is not practical for production purposes. Therefore, means of reducing the mixing requirements were investigated for use in low-energy mixing.

The Effect of Salt

Farinograph data from Part I indicated that the combination of salt with high lactose levels prolonged the mixing requirements of a dough. In the N50 Hobart the sourdough formula (pH 4.6) with 1.5 per cent added salt required 45 minutes of mixing to attain some development. Without salt **(Table III)** the mixing requirements were reduced more than 50 per cent to 20 minutes, which agrees with the farinograph data in Part I where mixing requirements were reduced by one-half when the salt was omitted. Without the addition of salt bread volume also improved because of better gluten development, hence the ability to retain the increased amount of CO_2 produced.

Salt is an essential bread ingredient both for flavor and for control of fermentation. The effects of delaying the addition of salt were investigated. The formula was made up without salt and mixing begun. The salt then was added after varying times of mixing. When salt was added during the early stages of mixing, further mixing caused the doughs to become somewhat slack and sticky. By withholding the salt until the last two minutes of mixing, this effect was diminished because the dough was well developed prior to adding the salt. In order to obtain optimum bread volume **Table III** shows that mixing time was reduced by one-half when salt was withheld until the last two minutes of mixing, providing the proof time was increased from 60 to 105 or more minutes. The problem with this method was that incorporating the salt into the developed dough during the latter stages of mixing was somewhat difficult. The coarse grained salt used in this work did not dissolve well, remained on the outside of the dough, and did not distribute evenly.

To circumvent the problem of the salt effect in low-energy mixing, a commercial sample of coated salt was evaluated as a salt substitute. The fat coating on the salt was designed to melt and release the salt during baking. Therefore, no salt or very little should have been released during the critical mixing period.

The coated salt was added at the beginning of the mixing period. Doughs were mixed for the same time as doughs mixed without salt or those in which the salt addition was delayed. As mixing progressed the doughs tended to become slack and sticky. This effect was similar to that observed when uncoated salt was used.

Table IV shows that more than half of the coating on the salt was released prior to baking. The CO_2 production of doughs made with coated salt was about half-way between doughs mixed without salt and those containing all the formula salt. The volume of bread made with coated salt also was low. Since the doughs containing coated salt were inadequately developed, the poor volume could have been caused by poor gas retention, a function of undermixing, as well as by low CO_2 production.

The Effect of Flour

The combination of HRS and HRW was used in an attempt to reduce the mixing requirements of the sourdough system. **Table V** shows that the combination of flours did not reduce mixing times significantly; moreover, loaf volumes and flour absorption were depressed relative to HRS. Dough made from HRW alone had low mixing times and absorptions and produced bread of reduced volume.

The Effect of pH and Lactose

Guy *et al.* (3) noted that the addition of lactic acid to doughs containing sweet whey (73 per cent lactose) dropped the dough pH from 5.0 to 4.6, depressed dough absorptions and bread volumes, and increased dough proof times. Bayfield and Young (2) found the pH of 5.1 to be optimum for their pan bread brew system. At pH 4.6, their doughs were fragile and tore easily. Bennett and Ewart (4) studied the reaction of acids with dough proteins. They theorized that acid destroyed salt linkages and caused molecules to unfold by mutual repulsion of positively charged side groups. Thus, the protein became an extended configuration lacking curls or kinks, and without normal stretch. Bennett and Ewart also added lactic acid to their doughs and found that at low concentrations loaf volume improved, and at higher concentrations, loaf volume decreased. They attributed their volume decrease to the reduced ability of the dough to expand, and to the tendency for gas cells to rupture rather than expand during baking.

Table V

Effects of Flour Types on the Mixing Requirements of Doughs and Loaf Volumes of Bread Mixed in the Hobart N50

Flour	Abs. (%)	Mixing Time (min.)	Fermentation (min.)	Proof (min.)	Specific Volume (cc/g)
100% HRS	57	2L 45S	40	60	2.8
100% HRW	54	2L 25S	40	60	2.3
100% HRW	54	2L 25S	40	90	2.3
50-50 HRS & HRS	55	2L 40S	40	60	2.4
50-50 HRW & HRS	53	2L 35S	90	90	2.4

L = low speed; S = second speed.

Table VI

Effects of pH on Mixing Times and Volumes of Sourdough Bread

pH	Mixing Time (min.)	Fermentation (min.)	Proof (min.)	Specific Volume (cc/g)
4.6	2L 40S	40	60	2.4
4.6	2L 25S	90	90	2.4
4.8	2L 25S	90	90	2.5
5.0	2L 15S	90	90	2.9

L = low speed; S = second speed.

Table VII

Effects of Cysteine on the Sourdough System

Flour	pH	Cysteine (ppm)	Mixing Time (min.)	Specific Volume (cc/g)
½ HRS, ½ HRW	4.6	—	2L 35S	2.4
½ HRS, ½ HRW	4.6	50	2L 25S	2.5
½ HRS, ½ HRW	4.8	50	2L 15S	3.1
HRS	4.6	—	2L 45S	2.8
HRS	4.6	50	2L 35S	2.7
HRS	4.6	80	2L 15S	3.0
HRS	4.8	80	2L 10S	3.3
HRS	4.7	80	2L 12S	3.2
HRS	4.8	120	2L 9S	3.2

L = low speed; S = second speed; all 90 min. fermentation time and proof times.

Farinograph data in Part I indicated pH was not an important factor in the mixing requirements of this sourdough system. The effects of pH were studied by mixing the dough system in the Hobart N-50 at pH 4.6, 4.8, and 5.0 controlled by addition of sodium acetate. The doughs were fermented, proofed, and then baked into bread. **Table VI** shows that the dough system (50-50 HRW and HRS flours) required less mixing as pH increased. Specific volume was improved as pH increased.

These observations agree with previously reported work (2,3), but not with our farinograph data. In the farinograph the effects of acid were not so apparent. This could be due to the relatively efficient mixing action of the farinograph. At higher farinograph speeds the dough developed faster with acid present. Then too, farinograph data do not always relate well to mixing data. Miller *et al.* (5) found a correlation of only 0.27 between the farinograph peak and the baking mixing time of 186 samples.

The addition of sodium acetate to increase the pH was not an acceptable means of reducing mixing requirements and increasing bread volume. The amount of buffer required to change the pH from 4.6 to 4.7 slightly altered the flavor of the bread.

To determine the interrelationships of lactose, salt and acid in low-speed mixing, the dough was made up with the equivalent amount of lactose, but without acid. The dough required 30 minutes mixing in the Hobart N-50. The specific bread loaf volume was 3.5 cc/g. This again indicated that lactose and salt did not contribute to the mixing requirements. The addition of acid to the system containing salt and high levels of lactose produced a dough which required more than 30 minutes mixing. This acid-containing dough produced bread with slightly reduced volumes.

The Effect of Cysteine

The addition of cysteine to the sourdough system made with both the HRS and the combination of HRS and HRW flours significantly reduced mixing requirements, and increased bread volume. **Table VII** shows that the addition of 80 ppm cysteine reduced the mixing requirements of the HRS dough system by 66 per cent. With the 80 ppm cysteine, the dough had better stretch and improved handling qualities, indicating better gluten development. Cysteine did not modify the taste, texture, and color characteristics of sourdough bread. The addition of 120 ppm of cysteine did not improve the dough properties over the addition of 80 ppm.

The addition of cysteine to the dough system at pH 4.8 and 4.7 cut mixing requirements further and improved volume, which agrees with the farinograph data. Cysteine reduces dough mixing requirements by promoting the disulfide-sulfhydryl interchange. The energy required to develop the dough is reduced when cysteine chemically splits the disulfide bonds (6). High-speed mixers break these bonds through mechanical action.

The function of mixing is to promote hydration of the more soluble gliadin proteins and to break down the undispersed aggregates so that protein-protein interactions can build the dough matrix. Mullen and Smith (7) found that the rapid release of the soluble protein, combined with the mechanical breakdown of the insoluble protein components (glutenin) tended to shorten dough development time. The large glutenin complex is held together by extensive disulfide bonding. With salt and lactose present in an acid dough system the problem of breaking these bonds and reducing the size of the complex apparently is compounded. Vigorous mechanical action, as in the Hobart A-200 mixer, breaks down the complex and dough development takes place rapidly. Low-energy mixers require the aid of chemical reduction to reduce the glutenin to smaller units and, hence promote development.

Conclusions

This study indicates that high levels of acid whey alter the mixing requirements of a dough system. Acid, salt and high levels of lactose all tend to increase the dough mixing requirements. They are problem factors only with low-speed, low-energy mixing. The acid whey and vinegar sourdough system requires high-speed, high-energy mixing for optimum development. Make-up in a less efficient, low-energy mixer necessitates extended mixing or some formula modifications. The addition of 80 ppm cysteine reduces the mixing requirements without changing the flavor characteristic of the bread. Because of the slow solubilization of salt granules added to a well developed dough, withholding the addition of salt to the latter stages of mixing also reduces the mixing requirement in a low energy mixer.

In the farinograph, the effects of acid were not so apparent. This could be due to the relatively efficient mixing action of the farinograph. At higher farinograph speeds the dough developed faster, which indicated a more rapid breakdown of the insoluble glutenin component, hence a faster development.

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